The Implications of Incorporating Uncertainty into Fisheries Management for Policy Makers

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Abstract.- The inclusion of uncertainty in determining fleet size is particularly important in determining excess capacity in a fishing fleet. Multinomial logit, a technique developed to account for uncertainty in the fishery management process, is used to determine the probability of an event occurring under the biological and market conditions existing at a point in time. In the case of the Gulf of Mexico shrimp fishery, the probability of entry and exit of fishing vessels can be used to estimate fleet size as well as the optimum scale of production for an individual fishing craft in a common property fishery under various proposed management regulations. It is also important in determining the response of the fleet to proposed regulations designed to reduce excess capacity through the reduction of vessels and their scale of operation. However, predictions of fisher behavior based on constant stock abundance indices differ from predictions incorporating the unknown variable stock abundance indices; another form of uncertainty. The implication is that the fish stock and the effort effects need to be determined simultaneously to accurately predict the response of a fishery to a proposed management regulation.

Introduction

Bioeconomic modeling sometimes requires a number of separate systems to be in equilibrium. Fish stocks which act as constraints on the production of fish are subject to uncertain stock-recruitment relationships. Individual recreational and commercial fisher behavior is determined by goals and objectives that are not well understood. Market allocation mechanisms are distorted in unknown ways by management regulations that distribute fish between different user groups based on historic catch rates determined in markets characterized by negative externalities. Uncertainty is prevalent in harvesting sector prices, costs, catch rates, equipment performance, weather, quality of inputs, and fishery management institutions. Processors face supply and demand uncertainty from changes in fishery regulations, imports, exports, and levels of aquaculture production, which are further exacerbated by the nonexistence of futures markets for nearly all fishery products. Consumer demand uncertainty exists because the quality of fishery products is determined post consumption, seafood safety and health risks are unknown prior to consumption, and per capita income levels are known only as a national index.

However, since Bishop (1978) developed the safe minimum standard (SMS) approach to public decisions, techniques have been developed to account for uncertainty in the fishery management process. For example, multinomial logit is used to determine the probability of an event occurring under the biological and market conditions existing at a point in time. In the case of the Gulf of Mexico shrimp fishery, the probability of entry and exit by fishing vessels can be used to estimate fleet size as well as the optimum scale of production for an individual fishing craft in a common property fishery under various proposed management regulations (Ward and Sutinen 1994). The inclusion of uncertainty in determining fleet size is particularly important in determining excess capacity in a fishing fleet. It is also important in determining the response of the fleet to proposed regulations designed to reduce excess capacity through the reduction of vessels and their scale of operation.

However, predictions of fisher behavior based on constant stock abundance indices differ from predictions incorporating variable stock abundance indices, which is another form of uncertainty. The implication is that the fish stock and the effort effects need to be determined simultaneously to accurately predict the response of a fishery to a proposed management regulation.

Sources of Uncertainty

Fishing effort is a function of ex-vessel prices, harvest or operating costs, and the abundance of fish. While the emphasis of the National Stock Assessment Workshop is on the uncertainty in stock abundance and biological reference points, other forms of uncertainty in the fishery management problem also exist. Ex-vessel prices, for example, vary due to changes in import levels caused by new sources of supply such as increased production from aquaculture or the discovery of new shrimp fishing grounds. The development of new substitute or complementary products or changes in existing products can affect ex-vessel prices. In addition,

The views expressed herein are those of the author, not necessarily NMFS' changes in the levels of consumer income can cause demand for a fishery product to change and affect its price. Other factors that can affect the demand for a fishery product include changes in the perceptions of food quality and health aspects of food. Processor market structure can impact ex-vessel prices. Vertically integrated firms for example can reallocate profits from the harvest sector to the retail sector by reducing the ex-vessel price it pays internally. In fisheries, the lack of futures markets that allow for price hedging which smooth price fluctuations can result in increased variability in ex-vessel prices.

Operating costs are also subject to variation over time. Changes in the supply of factor inputs and their prices are due to demand by competing industries for the same input. Inputs that are traded in world markets such as fuel can have price changes influenced by events in foreign countries. Fuel costs can change as a result of embargoes, wars, economic growth and recession in the world economy, and by changes in the availability of substitute sources of energy. Changes in the quality of the inputs can cause relative costs to increase. As quality declines with a constant price, other costs such as maintenance and repair will increase or the input might have to be used in greater quantities to offset the decline in quality causing total operating costs to increase. Finally, declines in the stock abundance can cause the relative cost per pound of fish harvested to increase even though cost per unit of effort is constant. Other sources of uncertainty that can affect both prices and harvesting costs include changes in equipment performance, weather, and predator-prey and competitor species relationships.

A major source of uncertainty is the fishery management regulations designed to control harvest levels in common property, domestic fisheries. Command and control fishery management regulations such as total allowable catch (TAC) regulations, size limits, trip limits, and closed seasons or areas, can exacerbate the race-for-fish. Open access management of common property fishery resources can result in excess capacity and over capitalization in the domestic fishing fleet that increases harvesting costs. Even when limited entry is strictly enforced, capital stuffing can occur within the existing fleet. As capital investment increases, fishing costs rise and the fishing season if managed under a TAC becomes shorter. The same volume of fish is landed in shorter periods of time and can depress fresh fish market prices, and create a frozen fish market that sells a lower quality product at a lower market price while the fishery is closed. If the restrictive TAC is successful in conserving the fish stock, the race for fish and its effect on market prices and harvesting costs are exacerbated as the stock abundance increases.

Gulf of Mexico Shrimp Fishery

The Gulf of Mexico shrimp fishery is one of the most valuable fisheries in the United States and as a result also one of the most closely studied and monitored. However, even in fisheries such as shrimp with extensive data collection and quality control programs, uncertainty can still remain a problem. Three separate estimates of fleet size can be derived depending upon which data set collected and maintained by the National Marine Fisheries Service is used (Ward and Nance 1994). The vessel operating units file (VOUF) provides a higher annual estimate of fleet size based on gear type reported on board the fishing craft than the shrimp landings file (SLF) which is based on reported landings. A third and lower estimate of fleet size is developed from a comparison of the SLF and VOUF data files. Consolidated records and incomplete reporting as well as coding errors can account for these different estimates of fleet size in the shrimp fishery.

Another estimate of fleet size can be generated by comparing vessel activity over time. Full-time vessels are identified as operating in the fishery for three consecutive years. Entering vessels operate in the fishery in the base year and in the subsequent year, but not in the preceding year. Exiting vessels operate in the base year and in the preceding year, but not in the subsequent year. According to this definition, an annual average of 20 percent of the fleet consists of vessels that are entering or exiting the fishery (Ward and Nance 1994). More importantly, entry and exit behavior is occurring simultaneously in any given year. Some of this behavior can be explained by the heterogeneous nature of the fishing fleet. However, this behavior is also caused by socio-cultural attributes that affect fishers' decisions. When facing the same biological and market conditions in a similar fishing craft, two fishers may make different decisions about participating in the fishery. There will always be unobservable characteristics that vary among fishers that cause uncertainty in determining their behavior. This behavior can be modeled using multinominal logit techniques to estimate the probability that an individual vessel will enter, remain in, or exit the fishing fleet.

Constant Stock Abundance

The probability of entry-exit behavior in the Gulf of Mexico shrimp fishing fleet has been estimated using this multinominal logit estimation technique. These probabilities can be used to determine how fishers will behave under different proposed management regulations, the resulting size of the fishing fleet that results from this behavior, and the resulting scale of operation within the fleet. For example, Table 1 indicates how the probabilities of entry, remain in the fishery, and exit,

Table 1. Estimated probability of entry and exit for an individual vessel in the Gulf of Mexico shrimp fishery.

Entry Vessel Length	Entry new entrant	Remain switch gear	Exit in fishery	Exit switch gear	left fishery
25	0.0255	0.0012	0.9511	0.0026	0.0195
26	0.0245	0.0011	0.9513	0.0027	0.0203
27	0.0236	0.0011	0.9513	0.0029	0.0211
28	0.0227	0.0010	0.9513	0.0030	0.0219
29	0.0219	0.0010	0.9513	0.0031	0.0228
50	0.0125	0.0006	0.9420	0.0052	0.0397
51	0.0122	0.0006	0.9414	0.0053	0.0405
52	0.0120	0.0005	0.9408	0.0054	0.0413
53	0.0117	0.0005	0.9401	0.0055	0.0421
54	0.0115	0.0005	0.9394	0.0056	0.0429
55	0.0113	0.0005	0.9388	0.0057	0.0437
100	0.0061	0.0003	0.9048	0.0100	0.0790
110	0.0055	0.0003	0.8969	0.0108	0.0866
120	0.0050	0.0002	0.8890	0.0116	0.0941
130	0.0046	0.0002	0.8812	0.0124	0.1015
150	0.0040	0.0002	0.8658	0.0140	0.1161

are affected as vessel size changes for a given set of biological and market conditions. The probability of an entry by a fishing vessel either as a new entrant to the fishery or by an existing vessel switching gear declines as vessel size increases. The probability of exiting the shrimp fishery increases either by leaving the fishery or by switching to another gear as vessel size increases. Although the highest of the five categories indicate a tendency for the fleet to remain unchanged, the probability of remaining in the fishery also declines as vessel size increases. That is, for this set of economic conditions existing in the fishery, the trend is for smaller vessels to replace larger vessels in the Gulf of Mexico shrimp fishery.

These probabilities can also be used to determine how fleet size will change under different economic conditions or for various proposed fishery management regulations when combined with other economic analyses under an assumption of constant stock abundance. In Figure 1, the impact of access rights on fleet size is determined. First, the fishing fleet is allowed to come to a long-run equilibrium between years zero and sixty-eight. Once the fleet has stabilized at approximately 3,100 vessels, the regulatory change is introduced (Figure 1a). This results in a decline in fleet size to about 2,600 vessels over the next twenty-two years. This decline in fleet size accounts for the variability in prices due to changes in imports and domestic landings (Keithly *et al.* 1993). In Figure 1b, the effect of the proposed access rights program on the shrimp fleet causes a decline in fleet size while ex-vessel prices increase from approximately $1.60 per pound to $1.81 per pound. This price increase results in an increase in the landings of individual shrimp vessels in Figure 1c which results from incorporating operating costs and production into the shrimp model (Ward *et al.* 1995). This increase in ex-vessel price and landings is also accompanied by a decline in discarded finfish bycatch in Figure 1d. Although bycatch increases on a per-vessel basis because landings increase, this decline in total discarded bycatch is primarily the result of a reduction in the size of the fishing fleet (i.e., fewer vessels discarding finfish.)

This result occurs because the annual rent generated by the shrimp resource is internalized into the decision-making processes of the individual firm. The capturing of these rents changes the behavior of the individual fisher. While both entry into and exit from the fishery occurs, the number of fishers leaving the fishery out weights the number entering. While these rents benefit the nation, the benefits that accrue to individual fishers depend on how the access right is allocated initially. If it is in the form of an annual auction, then fishers pay for the access right and receive no direct benefit from the program. If, however, fishers are allocated transferable, annual coupons to land shrimp, then all the benefits of the program accrue to them. In this second case, the fishers who elect to leave the shrimp fishery are compensated by those who decide to remain in the fishery. In either case, the nation is better off under the access rights program than the open access fishery system assuming constant stock abundance.

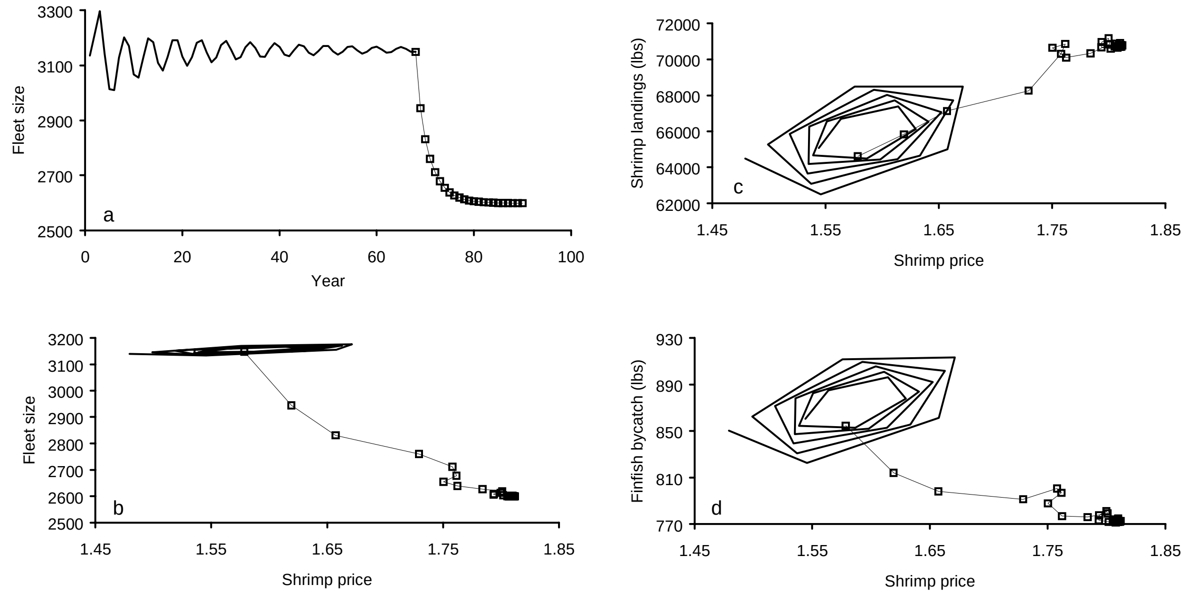

Figure 1. Impact of access rights on fleet size, shrimp landings and bycatch, in the Gulf of Mexico shrimp fishery. The lines with symbols depict the deterministic trajectories expected under the proposed regulatory program.

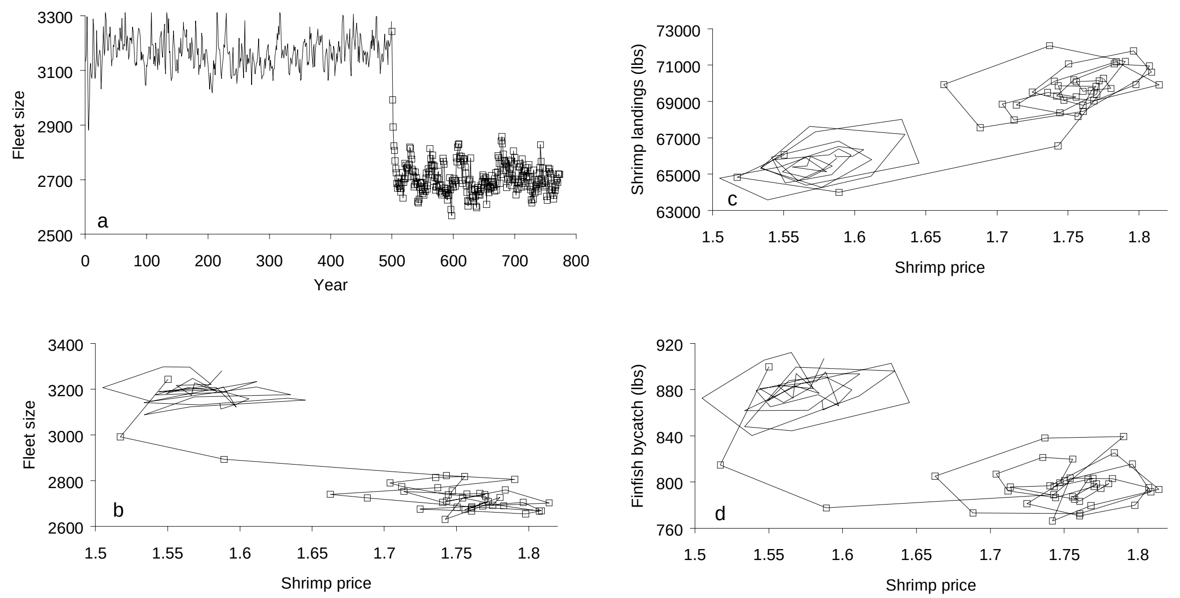

Figure 2. Impact of access rights on fleet size, shrimp landings and bycatch, in the Gulf of Mexico shrimp fishery, estimated with a variable abundance model. The lines with symbols depict the stochastic trajectories expected under the proposed regulatory program.

Variable Stock Abundance

Incorporating uncertainty about the vessel entry-exit decision with variation in ex-vessel price, cost, and individual vessel production levels allows the estimation of both short-run variation in fleet size over time as well as the long-run equilibrium fleet size. However, short-run variation in shrimp stock abundance needs to be addressed in determining how fleet size, costs, and benefits generated by the Gulf of Mexico shrimp fishery are affected by proposed fishery management regulations. The assumption of constant stock abundance is relaxed by incorporating a random number generator with mean 53.3 and a variance of 50. The mean reflects the average value from the Gulf of Mexico brown shrimp stock abundance index developed by the NMFS, Galveston Laboratory. The variance estimate is set to allow abundance to range between 29 and 71 over the course of the simulation. Although the intraseasonal changes in shrimp stocks are well documented and complex models explaining changes in stock size and migration patterns exist, the random number generator is used since an interseasonal stock recruitment relationship for shrimp is not presently available to incorporate into the model of the fishery.[1]

Figure 2 demonstrates how fleet size varies over time when variable stock abundance is incorporated into the model. Instead of coming to a long-run equilibrium over time, the fleet remains in disequilibrium until an arbitrarily determined point when the access right regulatory change is introduced (Figure 2a). Although the fleet declines in size after this change, it remains in disequilibrium responding to the random shocks caused by the variation in annual stock abundance.

This long run disequilibrium is not the only effect of variable stock abundance. In Figure 2a, the fleet size declines less than it did under the constant stock assumption. In Figure 2b, the decline in fleet size is accompanied by an increase in price to approximately $1.75 per pound; less than under the constant stock assumption. In Figure 2c, the variable stock abundance assumption causes individual vessel shrimp landings to increase, but by a slightly lesser amount than occurred under the constant stock assumption. This results in a larger decline in discarded finfish bycatch in Figure 2d than was found in the constant stock abundance scenario.

Stock abundance variability introduces changes in the behavior of fishers relative to their expected behavior when stock is assumed to be constant. While the direction of change is not affected, the magnitude of the change is affected. That is, the generation of rents in the fishery is reduced. In Table 2, cost and benefits are reported for the constant stock and variable stock scenarios. Increased stock variability does reduce net benefits from the adoption of the access rights program, depresses ex-vessel prices, and increases the level of bycatch reduction in the fishery.

Table 2. Impact of access rights on fleet size in the Gulf of Mexico shrimp fishery. PV = present value (in millions of dollars).

Stock	Tot. PV After	Tot. PV Before	PV Change	Cost: Benefit	%Bycatch reduction
Constant	4404.86	1940.49	2464.38	2.27	9.68
Variable	4289.35	1966.49	2322.86	2.18	11.42

Conclusions

Capturing uncertainty in fleet size using statistical techniques such as multinomial logit and variability in ex-vessel prices, and operating costs by incorporating them as endogenous variables in simulation models, enables better predictions of changes in fleet size under different proposed management regulations. However, while the direction of change remains the same, the magnitude of predictions of fisher behavior based on constant stock abundance indices differs from predictions incorporating variable stock abundance indices. As variability in stock abundance increases, so does variability in the estimated equilibrium values of the dependent variables, and causes the ability of the models to accurately predict changes due to proposed management measures or changes in economic conditions to decline. The implication is that the fish stock and the effort effects need to be determined simultaneously to accurately predict the response of a fishery to a proposed management regulation.

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[1] The analysis of a brown shrimp stock recruitment model reported in Gulland and Rothschild (1984) was reviewed in Garcia (1983) and may have been a statistical artifact. Another stock recruitment analysis of brown shrimp by Parrack (no date) is reported to have found a statistically valid relationship, but was not available to be included in this analysis.